End-to-End Mission Autonomy

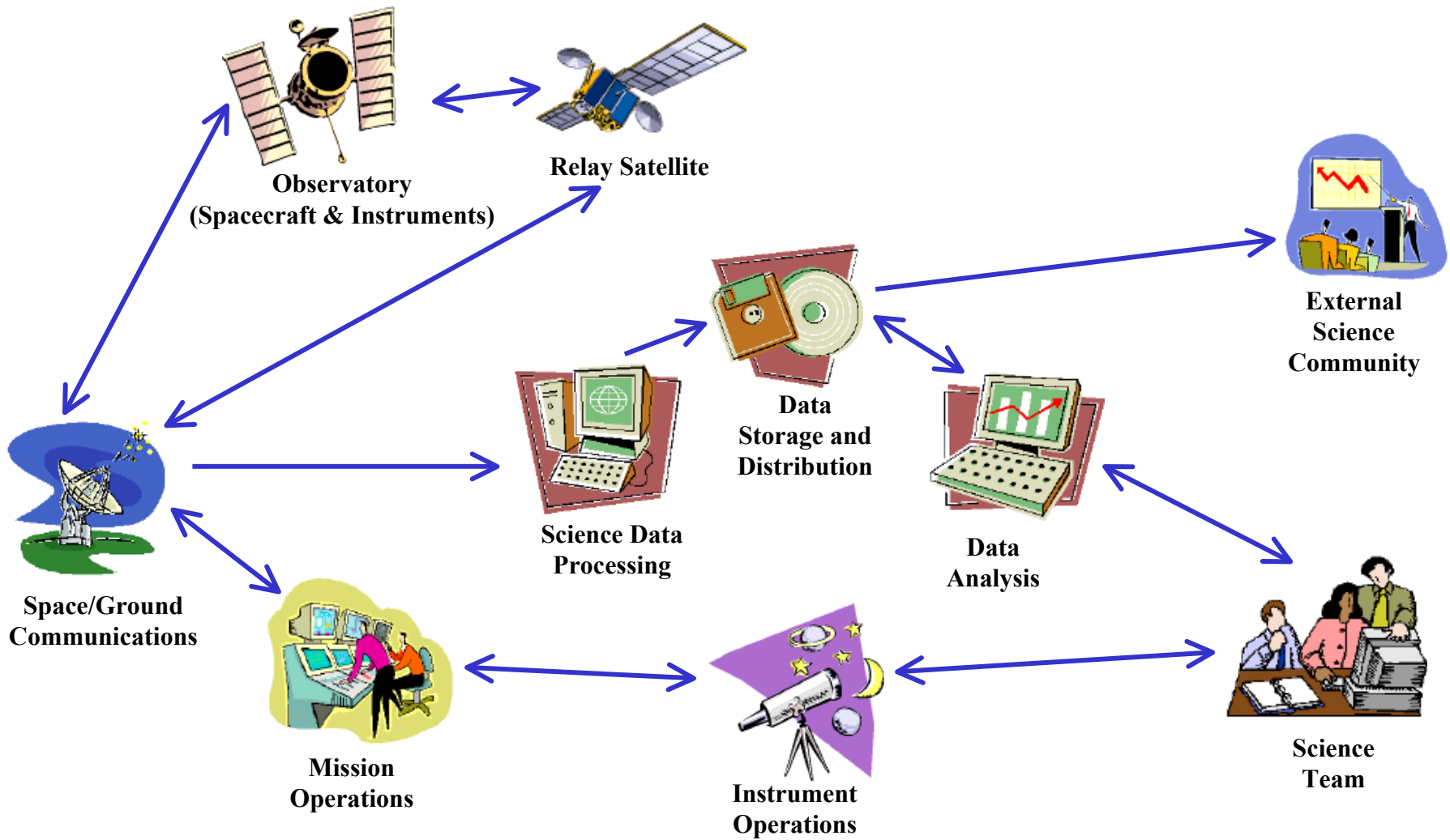# *GSFC / SOMO Technology Development Program Annual Review*

Barbie Medina

September 19 - 20, 2001

Agenda

- Work Area Overview

- External Coordination

- Common Planning and Scheduling System (ComPASS)

- Constellation Challenge

- Architecture for Constellation Management Automation (ACMA)

- Advanced Fault Detection Isolation and Recovery (AFDIR)

- Multi-Agent Systems (MAS)

- Instrument Remote Control (IRC)

- Onboard Studies

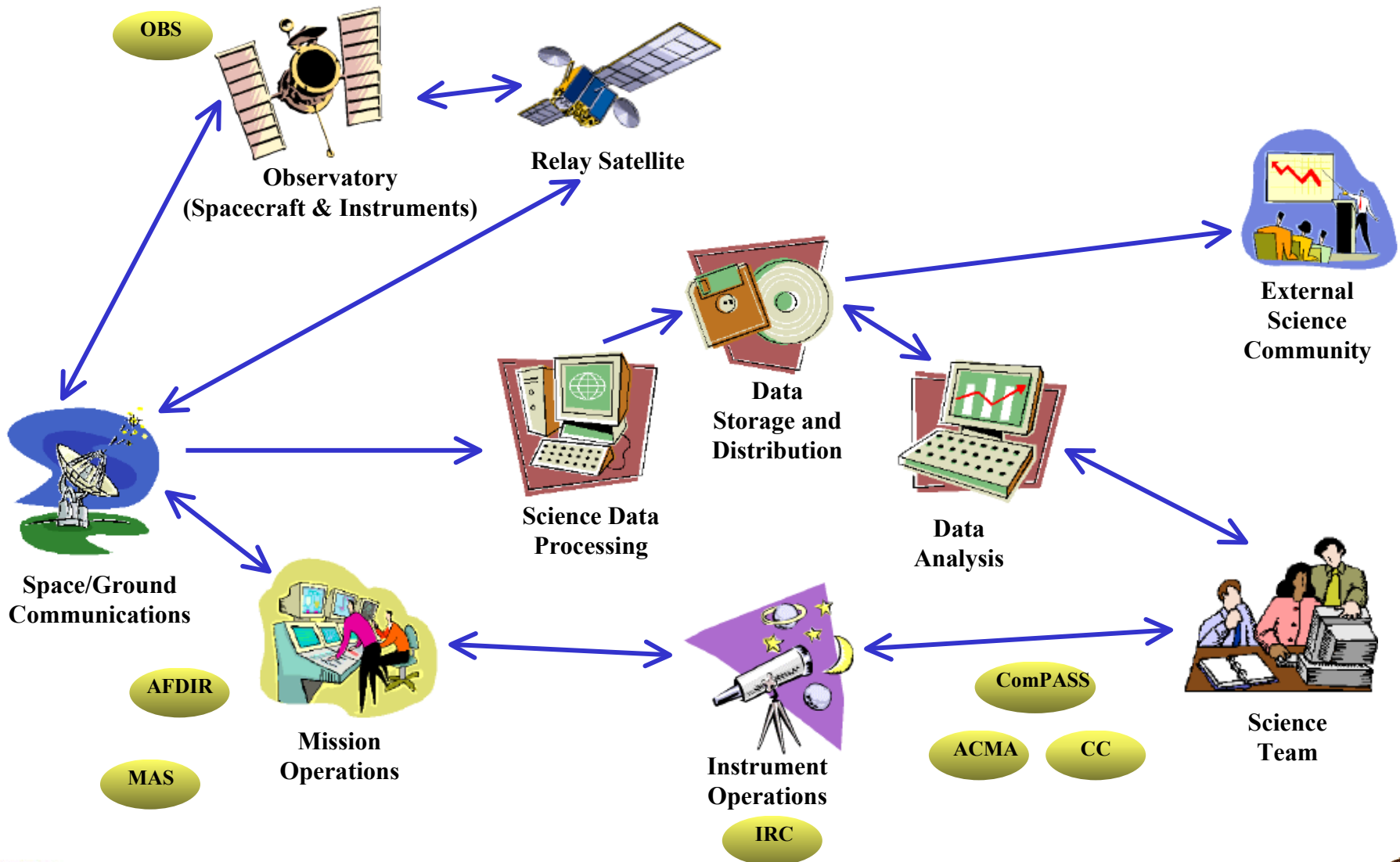- Work Area Accomplishments and Plans

End-to-End Mission Autonomy

Observatory (Spacecraft & Instruments)

Relay Satellite

Space/Ground Communications

Science Data Processing

Data Storage and Distribution

Data Analysis

External Science Community

Mission Operations

Instrument Operations

Science Team

End-to-End Mission Autonomy

- Objective
  - Significantly advance the automation of the end-to-end mission systems to improve science data collection, reduce development and operations cost, and enable constellation missions through transparent, autonomous mission operations.

- Work is being performed in the areas of:
  - Automated Planning & Scheduling
  - Automated Health and Safety Analysis and Control
  - Instrument Monitoring & Control
  - Onboard Studies
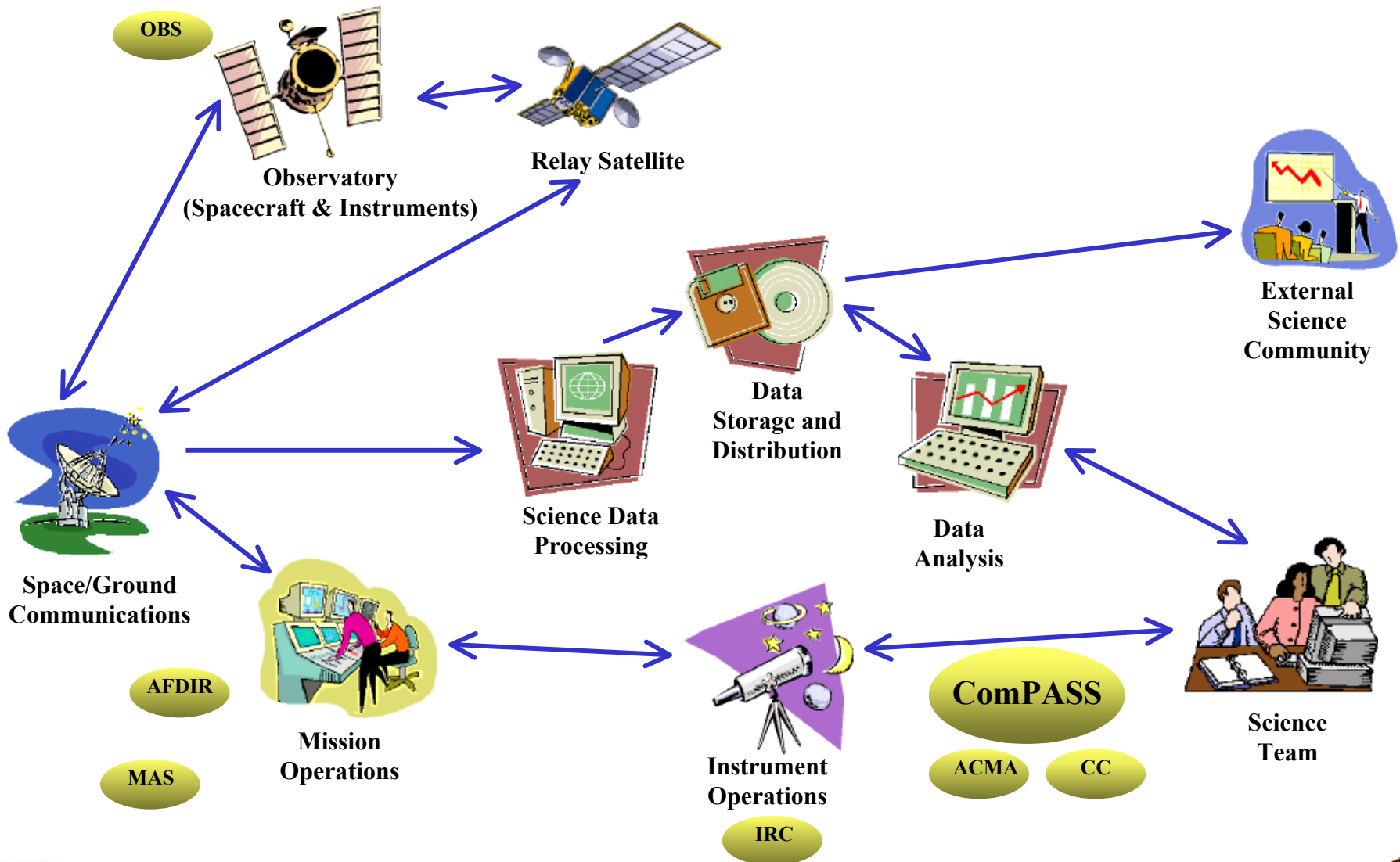
End-to-end Mission Autonomy

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AFDIR

MAS

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Operations

Instrument
Operations

IRC

ComPASS

ACMA   CC

Science
Team

End-to-End Mission Autonomy
External Coordination

Task	Partnership & Collaborations	Infusion and/or Transfer Plans
Instrument Remote Control	Infrared Astrophysics Branch (GSFC, 685) Center for Astrophysical Research in Antarctica (CARA) Stratospheric Observatory for Infrared Astronomy (SOFIA) Mesoscale Atmospheric Processes Branch (GSFC, 912) National Institute of Standards and Technology (NIST)	HAWC SAFIRE COVIR/Shuttle FIBRE NIST SHARC/Cal Tech
Agents Concept Testbed	JPL- Sanda Mandutianu GSFC- Bob Dutilly, the SOHO Mission Director	SOHO mission operations
Advanced Fault Detection, Isolation and Recovery	Hubble Space Telescope (HST)	HST Large Constellations
Onboard Studies		NGST KRONOS
Common Planning and Scheduling System	Space Telescope Science Institute (STScI) HST FUSE Chandra X-Ray Observatory Facility	HST FUSE Chandra
Constellation Challenge	JPL - ASPEN mission planning system ARC - RAILIST natural language software	ESDIS Large Constellations
Architecture for Constellation Management Automation	ARC – Remote Agent Planner GSFC – Formation Flying Testbed	MMS ST-5

Common Planning and Scheduling System

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ACMA   CC

Science
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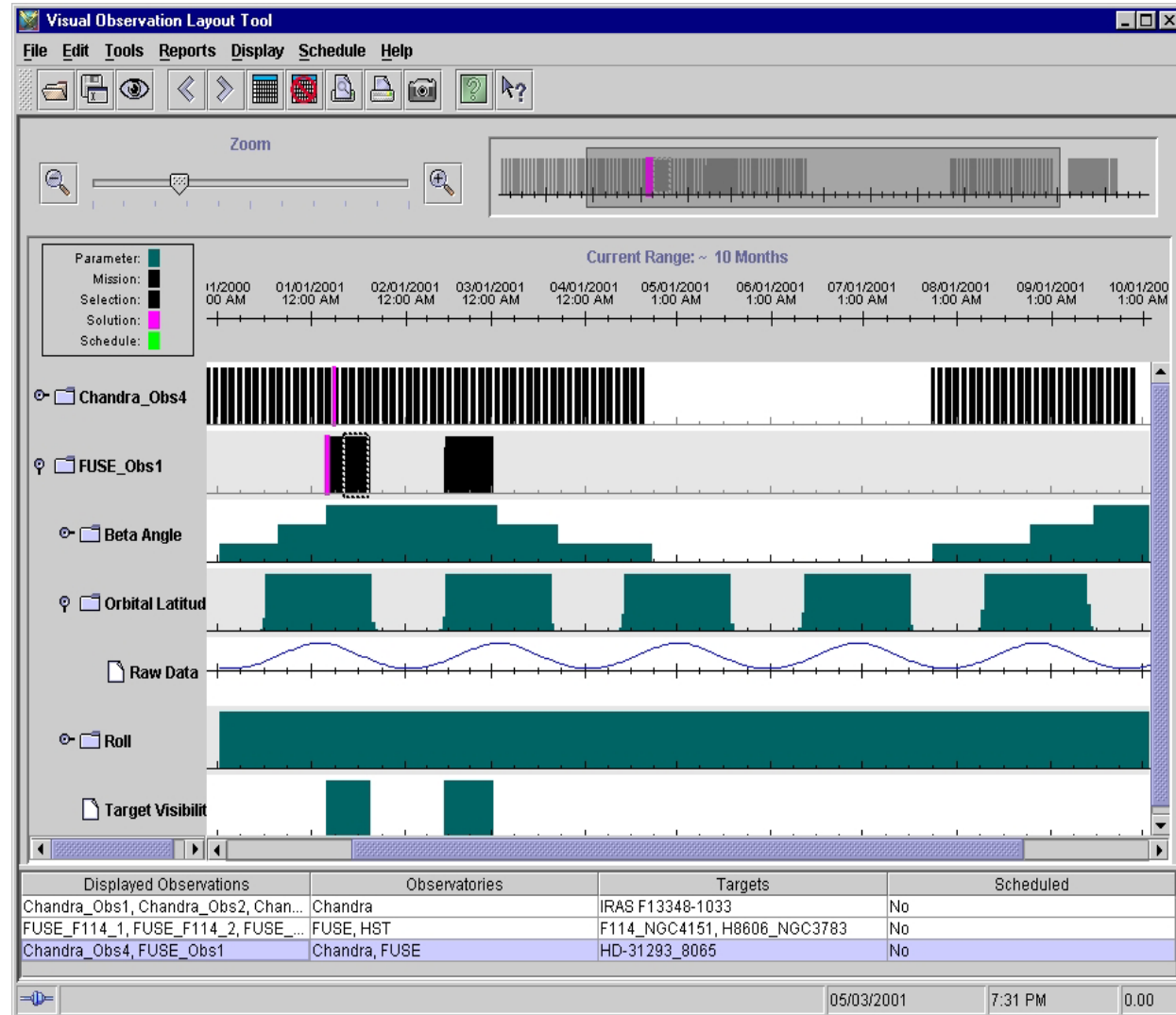# ComPASS Visual Observation Layout Tool (VOLT) Overview

- Summarized Description:
  - Provide a visual tool set for planning coordinated observations across multiple missions.

- Background / Need:
  - Planning and executing coordinated observations across multiple observatories is essential to realizing multi-length campaigns and meeting future space and earth science goals.
  - The current lack of automated planning tools makes coordinated observing across missions resource intensive and consequently limits science research.
  - The current process is tedious, error-prone, and provides the observers very little visibility into the schedulability of their proposed observations.

- Benefits / Significance:
  - Reduce the cost of mission planning through automation.
  - Simplify planning and increase efficiency by reducing the amount of manual collaboration.
  - Enable coordinated planning among independent observatories (create virtual observatory).
  - Enabling technology for heterogeneous constellation missions.

- Potential Customers: HST, FUSE, Chandra

ComPASS Visual Observation Layout Tool (VOLT) Schedulability Display

- Visual support for the planning of multi-mission observations

- Schedulability overview

- Time range selection capabilities to further constrain the problem domain

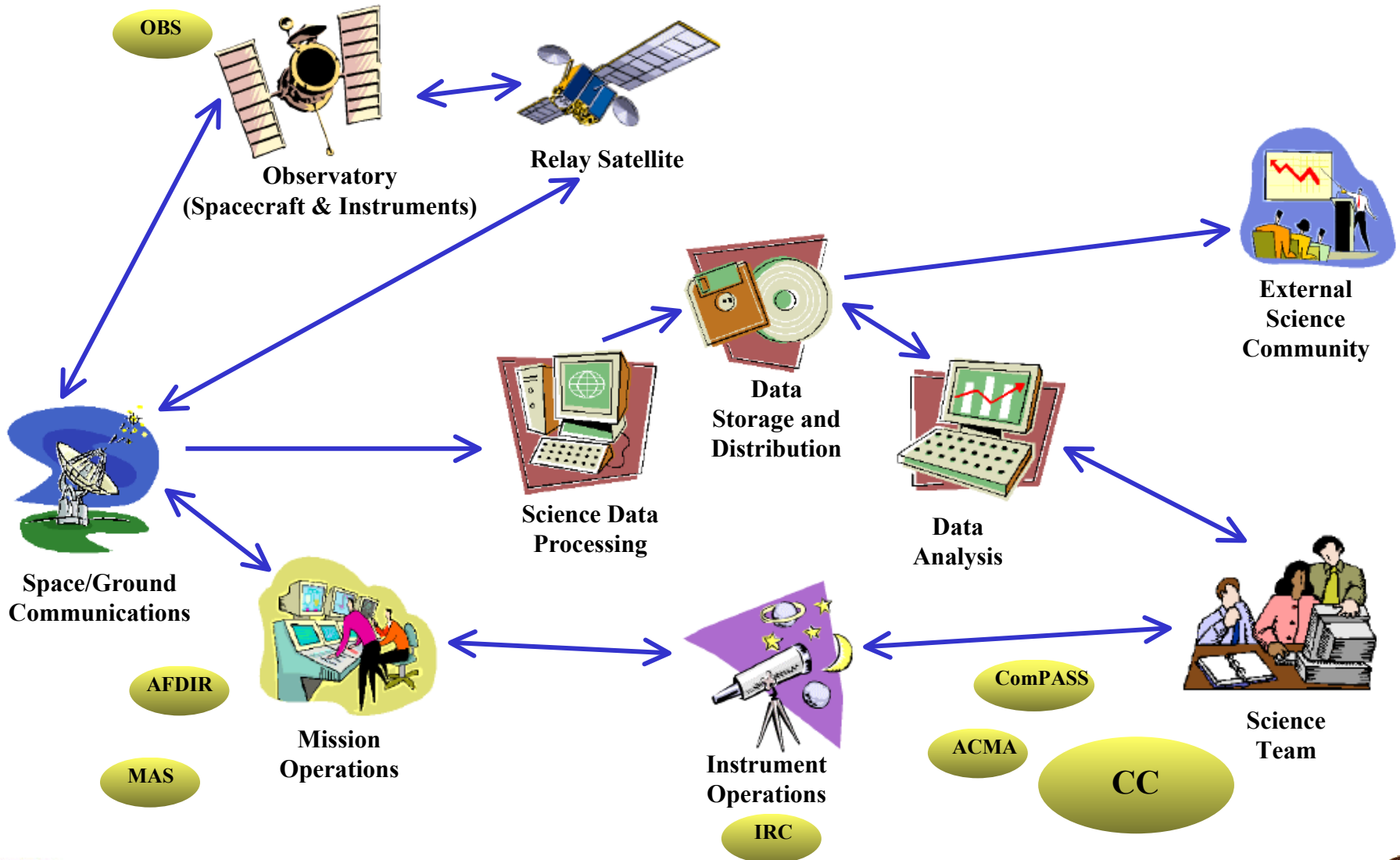- Constraint modification suggestions

The Schedulability Display

ComPASS Visual Observation Layout Tool (VOLT) FY01 Accomplishments / Plans

- FY01 Accomplishments
  - VOLT build 2.0
  - VOLT build 3.0 (mission set and interface extensibility)
  - VOLT build 4.0 (user coordination)
  - VOLT build 5.0 (ground-based observatory)

- FY 01 Plan vs. Actual Deviations
  - Work has proceeded as planned.

- Planned Accomplishments for FY02
  - Task was scheduled to complete in FY02
  - Task transitioning to GMSEC at a reduced funding level (down to 1 FTE).

Constellation Challenge

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Operations
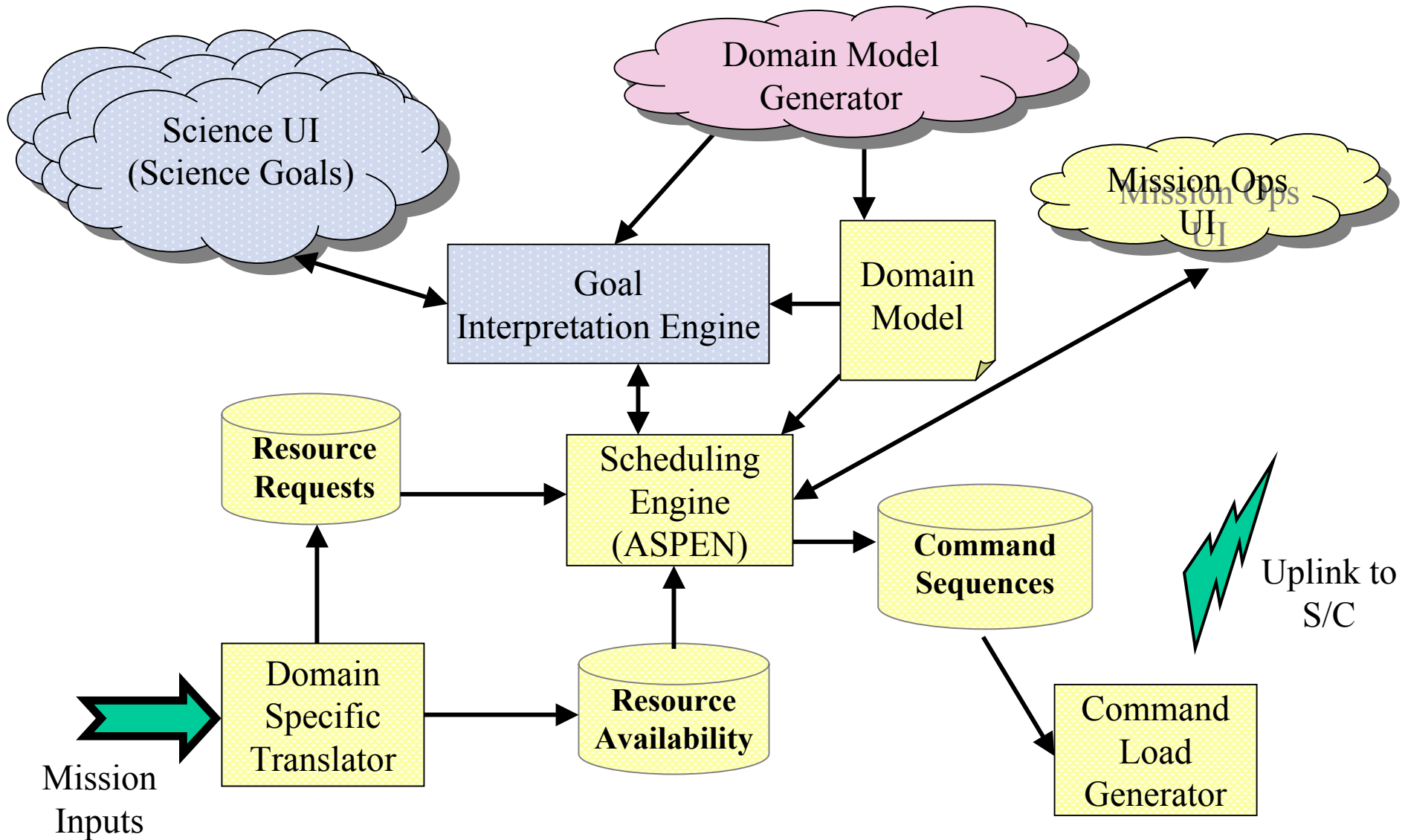
IRC

ComPASS

ACMA

CC

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Team

Constellation Challenge Goal Oriented Commanding (GOC) Overview

- Description:
  - Develop an automated process for converting high level goals to low level objectives (activities) and specific satellite command sequences.

- Background / Need:
  - Constellations may have as many as 100 spacecraft. NASA currently does not have experience in operating such missions. And, the best examples in industry have not successfully managed the mission operations costs.
  - In industry, mission operations staffing is increased proportionally to the number of spacecraft that must be monitored and controlled. NASA budgets cannot adopt this paradigm: thus new methods that increase the level of automation and autonomy must be developed.
  - Mission planning is currently a costly manual process. Automation of this function will benefit single spacecraft as well as multi-spacecraft missions.

- Benefits / Goal Metric:
  - Enable cost-effective operation of constellation missions.
  - Enable "opportunistic science" (near-real-time scheduling of unplanned science events).

- Potential Customers
  - Phase I will be utilized by ESDIS.
  - Phase II and beyond can be used by KRONOS.

Constellation Challenge Goal Oriented Commanding (GOC) Overview

Science UI
(Science Goals)

Domain Model
Generator

Mission Ops
UI

Goal
Interpretation Engine

Domain
Model

Resource
Requests

Scheduling
Engine
(ASPEN)

Command
Sequences

Uplink to
S/C

Mission
Inputs

Domain
Specific
Translator

Resource
Availability

Command
Load
Generator

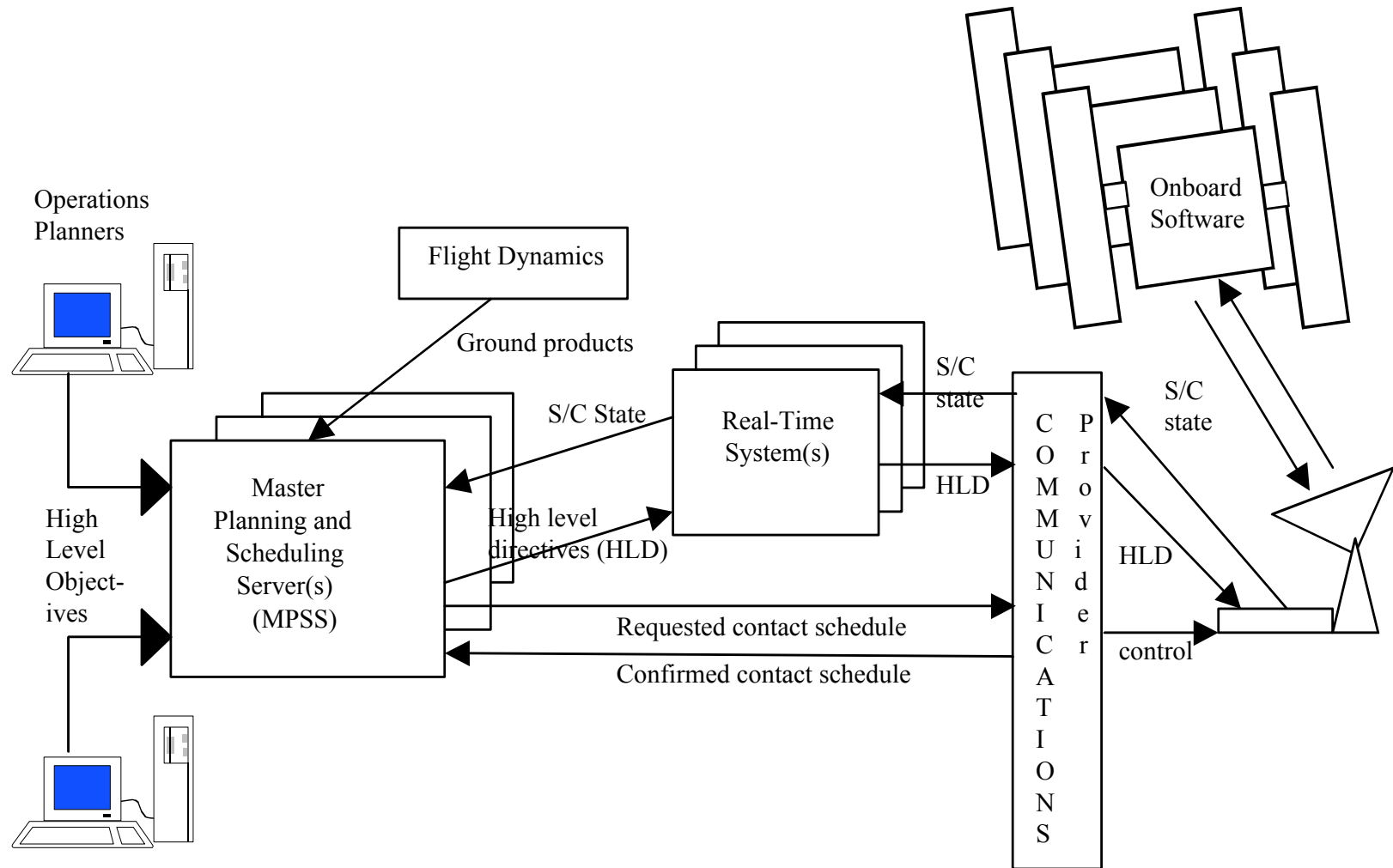# Constellation Challenge Goal Oriented Commanding (GOC) FY01 Accomplishments / Plans

- FY01 Accomplishments to Date
  - Obtained ASPEN software from JPL.
  - Completed and reviewed the project management plan.
  - Completed a draft ASPEN Interface Definition Document.
  - Completed the Concept of Operations and Supplemental Requirements Document.
  - Held the Concept of Operations and Supplemental Requirements Document Review.
  - Completed proof-of-concept demonstration
  - Completed release 2 of requirements
  - Completed preliminary design document
  - Completed prototype release (basic goal-oriented commanding functionality)
- FY 01 Plan vs. Actual Deviations
  - Since semi-annual review all work as proceeded as planned
- Planned Accomplishments for FY02
  - Task is transitioning to GMSEC.

Architecture for Constellation Management Automation (ACMA) Overview

- Project Goals:
  - The major project goal is to develop an architecture for an end-to-end constellation management system that addresses the unique challenges that upcoming constellation missions will face. Specific goals include:
    - Define the CMA architecture concept for satellite constellations identified as near-term missions by NASA/GSFC.
    - Define and document the functional, performance, operational and programmatic requirements of an end-to-end CMA for satellite constellations.
    - Design the CMA prototype to resolve the risk issues, study the constellation operations and prepare for a proof-of-concept demonstration of the CMA architecture.
    - Implement and integrate prototype components and demonstrate the end-to-end CMA prototype to constellation mission managers.
    - Implement Abstract Planner that will translate high-level goals into low-level commands.

- Benefits:
  - The primary benefit is to provide an automated constellation management architecture capable of handling various levels of spacecraft autonomy.
  - A secondary benefit is the anticipated cost savings that will be realized as required operations staffing levels are minimized.

- Potential Customers:
  - Code 583 is collaborating with the following customers to infuse CMA prototype into their ground system operations by:
    - Developing a prototype GUI used to input high level goals and objectives of the MMS constellation mission. The Abstract Planner to be demonstrated will interpret the high-level goals and execute a station scheduling algorithm to generate a conflict free schedule for the MMS constellation mission.
    - Talking to ST-5 Project about using station scheduling, and dynamic scheduling capability for the ST-5 constellation mission.

Architecture for Constellation Management Automation (ACMA) Approach

Operations Planners

Flight Dynamics

Onboard Software

Ground products

Operations Planners

High Level Object-ives

Master Planning and Scheduling Server(s) (MPSS)

S/C State

Real-Time System(s)

S/C state

High level directives (HLD)

HLD

COMMUNICATIONS Provider

S/C state

HLD

control

Requested contact schedule
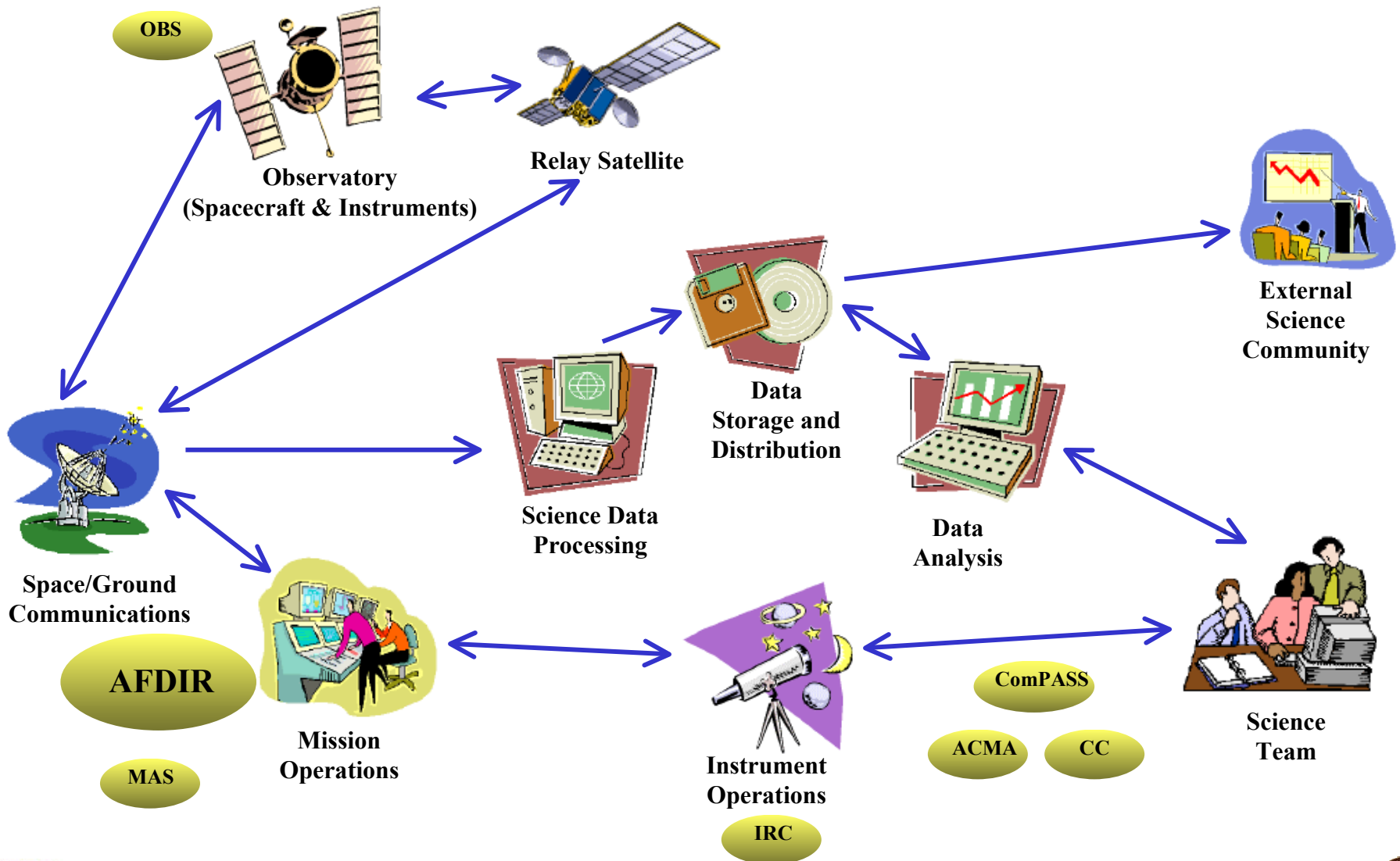
Confirmed contact schedule

ACMA Current Status and Accomplishments for FY01

Milestones	Date
•Completed prototype station scheduling capability with Universal Space Network (USN). Scheduling algorithm handles planning and replanning of station resources	December 2000
•Drafted constellation architecture requirements document	March 2001
•Surveyed Abstract Planner and Inference Engine components to incorporate into architecture	March 2001
•Demonstrated automated station scheduling capability with USN at GSFC Technology Showcase	June 2001
•Drafted white paper of inference engine criteria, search and evaluation results	June 2001
•Completed development of a prototype abstract planning algorithm and will demonstrate to Code 580 management team	September 2001

Future Plans for ACMA during FY02 and FY03

- Develop dynamic scheduler and constraint checker algorithm to enhance the mission planning functionality

- Develop a plug and play data base interface component within Automated Mission Planning System (AMPS) to execute COTS data base products

- Integrate AMPS components which include the abstract planner, the inference engine, data interfaces and the goal GUI

- Implement an object representation of spacecraft domain models and populate with simulated spacecraft data

- Create constellation domain models and populate models with simulated constellation data

- Develop a plug and play framework to integrate other NASA center's software and partner with these centers to increase the durability of ACMA

Advanced Fault Detection, Isolation, & Recovery

OBS

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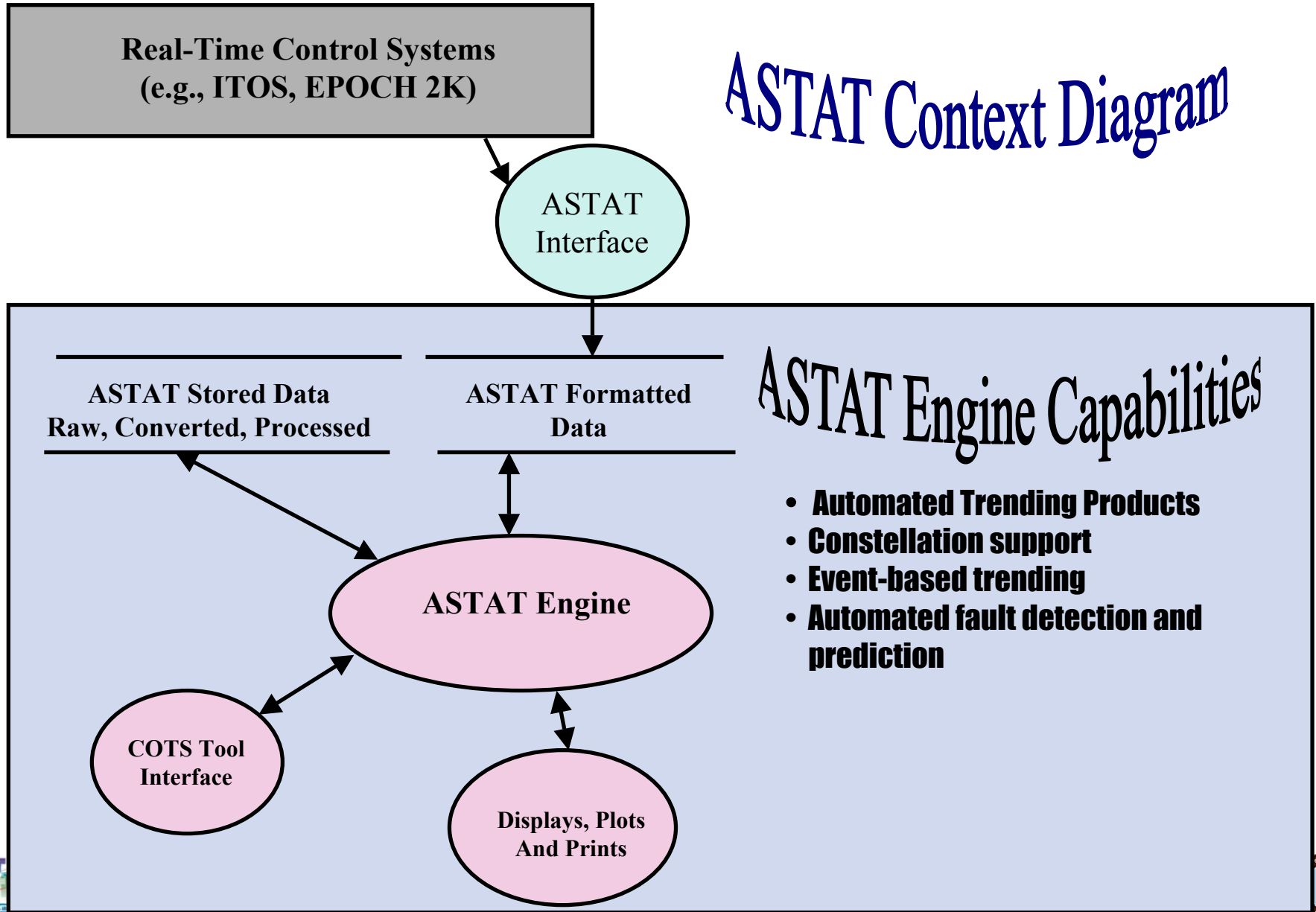IRC

ComPASS

ACMA   CC

Science
Team

AFDIR Advanced Spacecraft Trending and Analysis Tool (ASTAT) Overview

- Summarized Description:
    - Develop system to automate engineering trend product generation and to provide automated spacecraft fault detection and prediction from trending results.

- Background / Need:
    - Automation of trending functions and fault isolation is necessary for reducing operations costs for current single spacecraft mission.
    - Automation of trending functions and fault isolation is essential to operating constellation missions safely within a reasonable operations budget.

- Benefits:
    - Reduce manpower needed for spacecraft fault detection and recovery by automating analysis of spacecraft health and safety data (current methods are manual).
    - Reduce mission risk by predicting spacecraft faults before they occur.

- Potential Customers: HST, large constellations

AFDIR Advanced Spacecraft Trending and Analysis Tool (ASTAT) Overview

Real-Time Control Systems (e.g., ITOS, EPOCH 2K)

ASTAT Interface

ASTAT Context Diagram

ASTAT Stored Data Raw, Converted, Processed

ASTAT Formatted Data

ASTAT Engine Capabilities

ASTAT Engine

COTS Tool Interface

Displays, Plots And Prints

- Automated Trending Products
- Constellation support
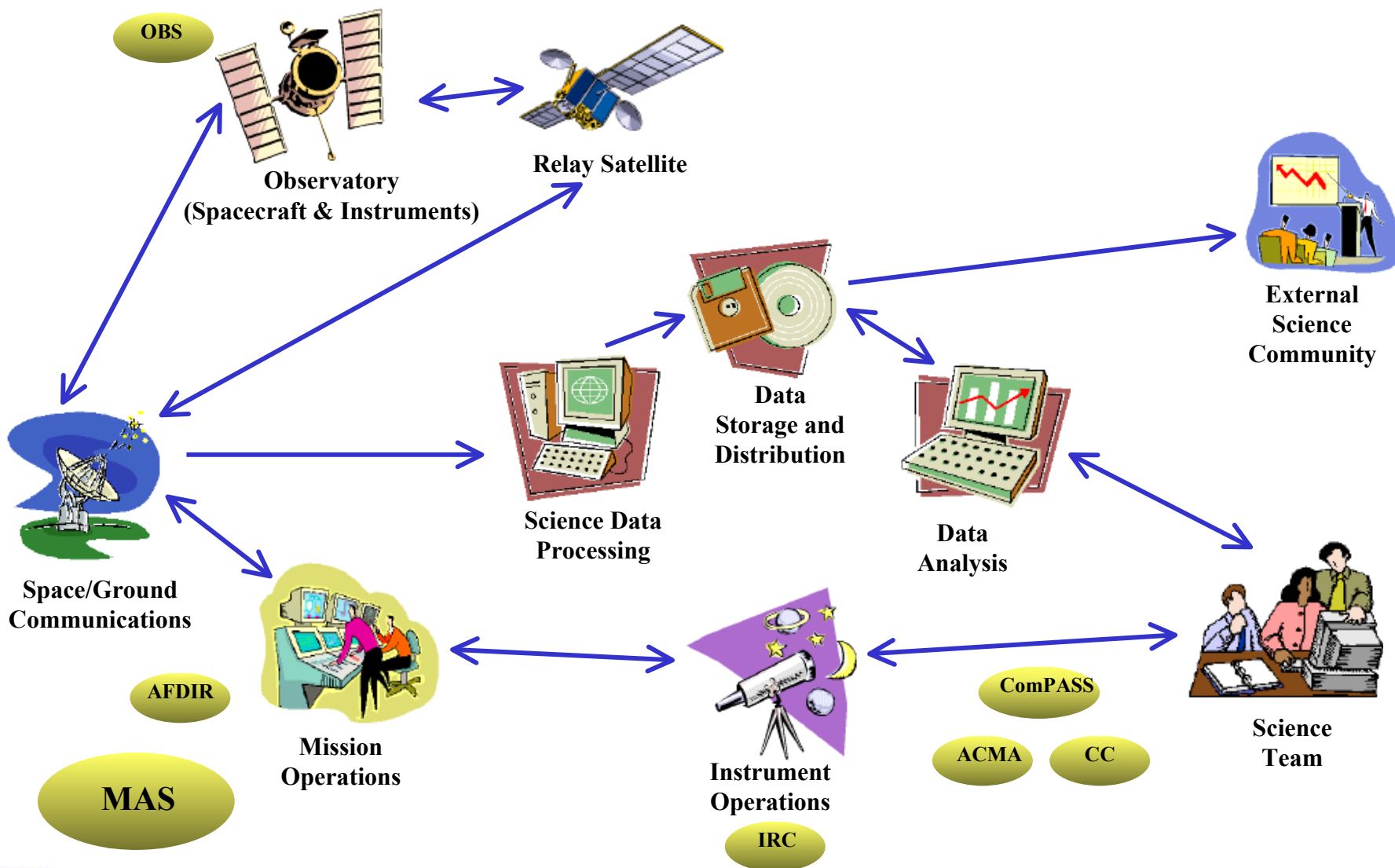- Event-based trending
- Automated fault detection and prediction

AFDIR Advanced Spacecraft Trending and Analysis Tool (ASTAT) FY01 Accomplishments / Plans

- FY01 Accomplishments to Date
  - Completed ASTAT requirements document.
  - Completed ASTAT operations concept.
  - Completed ASTAT Phase I design (plots and basic trending).
  - Completed ASTAT Phase I demonstration
  - Completed ASTAT Phase II design (fault detection and prediction).

- FY 01 Plan vs. Actual Deviations
  - The ASTAT phase II demonstration was cancelled in order to complete documentation and clean up of code in preparation for being cancelled at the end of the fiscal year.

- Planned Accomplishments for FY02
  - Task was scheduled to complete in FY03
  - Task is cancelled.

Multi-Agent Systems

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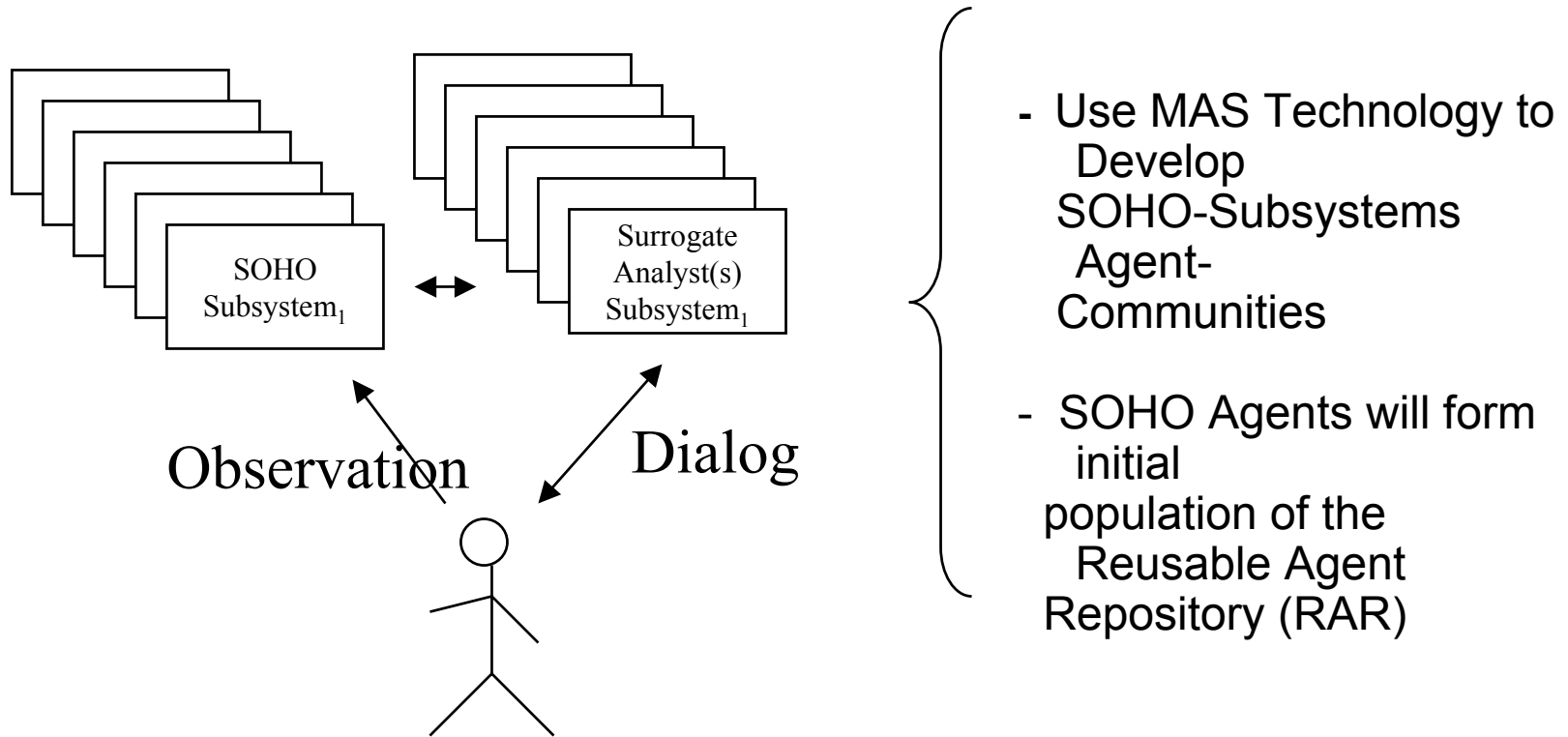IRC

ComPASS

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Team

Multi-Agent Systems (MAS) for Mission Control Overview

- Summarized Description:
  - To demonstrate the viability and cost-effectiveness of using MAS technology to support ground system development and operations. To develop and utilize a repository of reusable agents to develop future ground systems for a fraction of the time and cost when compared to using today's approaches.
  - To develop a MAS-based system for SOHO as a proof of concept.
  - To provide a comprehensive approach to "24 hour Lights-Out" operations.

- Benefits:
  - Robust and correct handling of mission objectives.
  - Quicker identification of problems and increased accuracy in problem analysis and handling over current manual approaches.
  - Reduction in the # of times remaining control center personnel become involved in detailed mission problem solving.
  - Reduction in cost of and development-time of future mission control systems through use of Reusable Agent Repository (RAR).

- Potential Customers: SOHO

Multi-Agent Systems (MAS) for Mission Control
SOHO Proof of Concept

SOHO Subsystem$_1$

$\longleftrightarrow$

Surrogate Analyst(s) Subsystem$_1$

Observation

Dialog

- Use MAS Technology to Develop SOHO-Subsystems Agent-Communities

- SOHO Agents will form initial population of the Reusable Agent Repository (RAR)
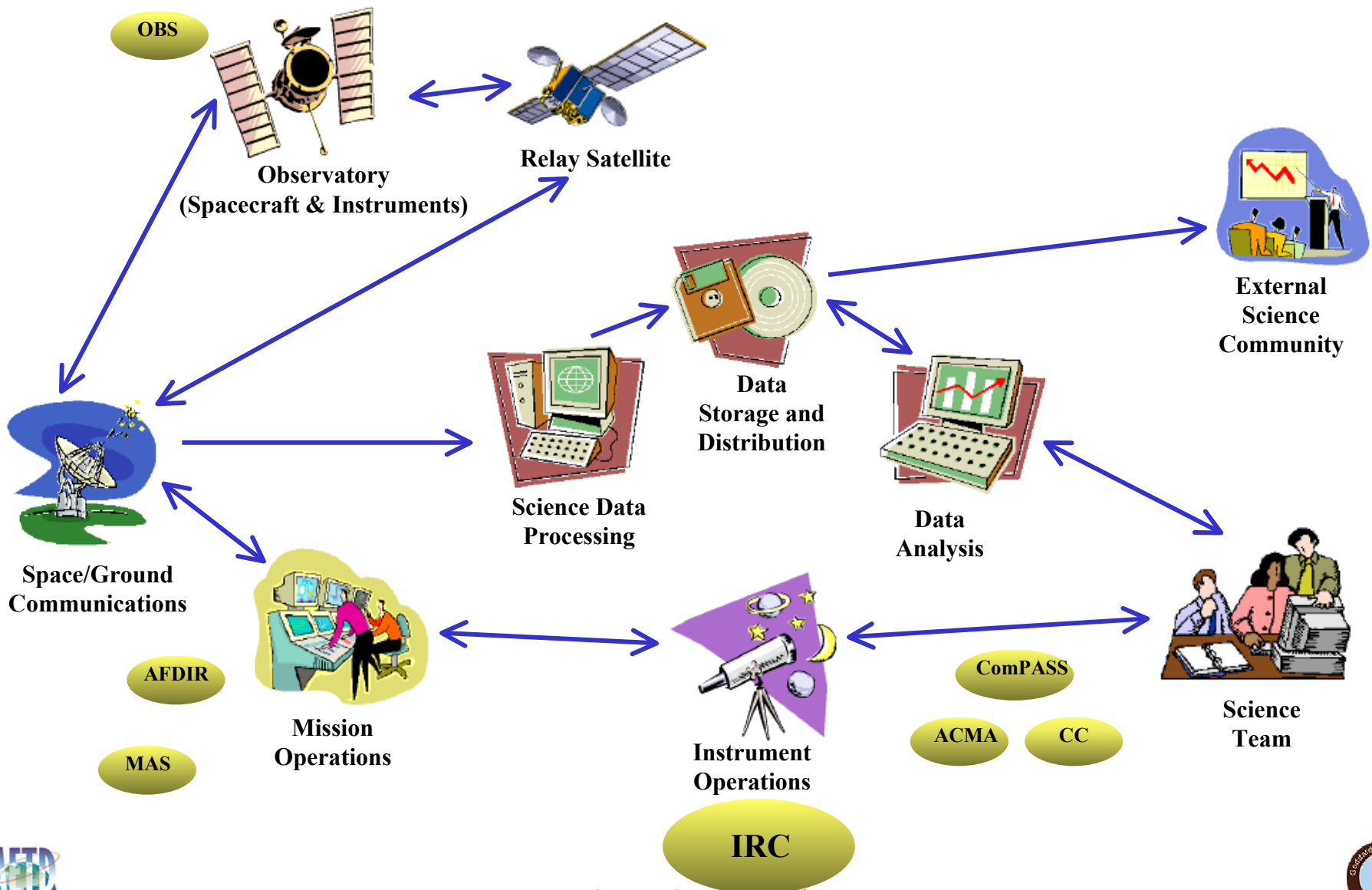
Minimal Control Center Personnel Staff

Multi-Agent Systems (MAS)
FY01 Accomplishments / Plans

- FY01 Accomplishments to Date
  - Established a working relationship with the SOHO Project.
  - Established collaborative activity with JPL to support the SOHO agent-development goals.
  - Developed and demonstrated the infrastructure for the SOHO agent and agent-communities.
  - Developed and demonstrated the SOHO Orbit Determination community.
  - Initiated development of RAR concept and operational scenarios.
  - Had papers accepted at FLAIRS and iSAIRAS conferences on this activity.
  - Demonstrated prototype agent for Attitude Determination.
  - Improved agent modeling visualization components.
- FY 01 Plan vs. Actual Deviations (since semi-annual review)
  - The demonstration of the tape recorder subsystem is cancelled due to a budget cut and in order to complete documentation and clean up of code in preparation for being cancelled at the end of the fiscal year.
- Planned Accomplishments for FY02
  - Task is cancelled

Instrument Remote Control

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IRC

Instrument Remote Control
Overview

- Summarized Description:
  - Deliver a cross-platform, distributed adaptive framework that provides remote mission configuration, control, monitoring, simulation, and analysis.

- Background / Need:
  - The most successful mission operations automation has come from the use of the same tool throughout the mission lifecycle, beginning with spacecraft I & T. For more strides to be made in automation engineers need be able to build knowledge and automation controls during instrument development and bench testing.
    - Current instrument control software does not provided a framework to build or interface to higher mission services and automation.
  - There was a need for a new architecture to shorten development cycles by increasing reuse and reducing integration time, and thus enabling more frequent missions.

- Benefits:
  - Reduce mission operations costs via:
    - Enabling engineers to begin building mission automation controls during instrument development and bench testing.
    - Enabling a new era of reusable, object oriented flight software that enables or compliments mission services on the ground.
    - Facilitating interoperability among mission components, leading to increased capabilities and easier insertion of new technology.
    - Enabling increased end-to-end mission automation via an advanced software framework and dynamic paradigm.
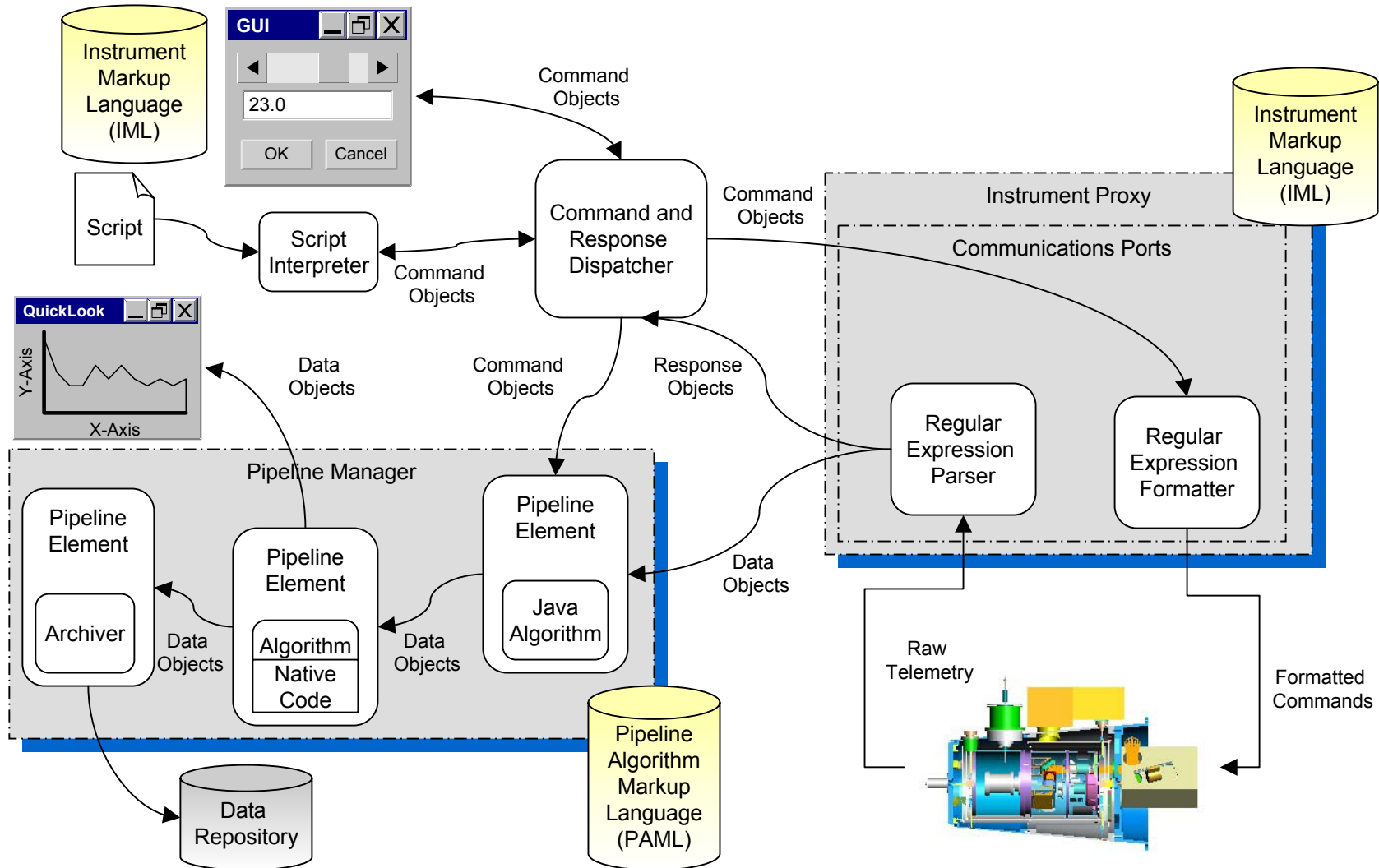
- Customers: HAWC, SAFIRE, COVIR, FIBRE, SHARC, NIST

Instrument Remote Control
Overview

Instrument Markup Language (IML)

GUI — _ □ X
◄ ▮ ►
23.0
OK   Cancel

Script

Script Interpreter

Command Objects

Command and Response Dispatcher

Command Objects

Command Objects

Instrument Proxy

Communications Ports

Instrument Markup Language (IML)

QuickLook _ □ X

Y-Axis

X-Axis

Data Objects

Command Objects

Response Objects

Regular Expression Parser

Regular Expression Formatter

Pipeline Manager

Pipeline Element

Pipeline Element

Archiver

Data Objects

Algorithm

Native Code

Data Objects

Pipeline Element

Java Algorithm

Data Objects

Data Objects

Raw Telemetry

Formatted Commands

Data Repository

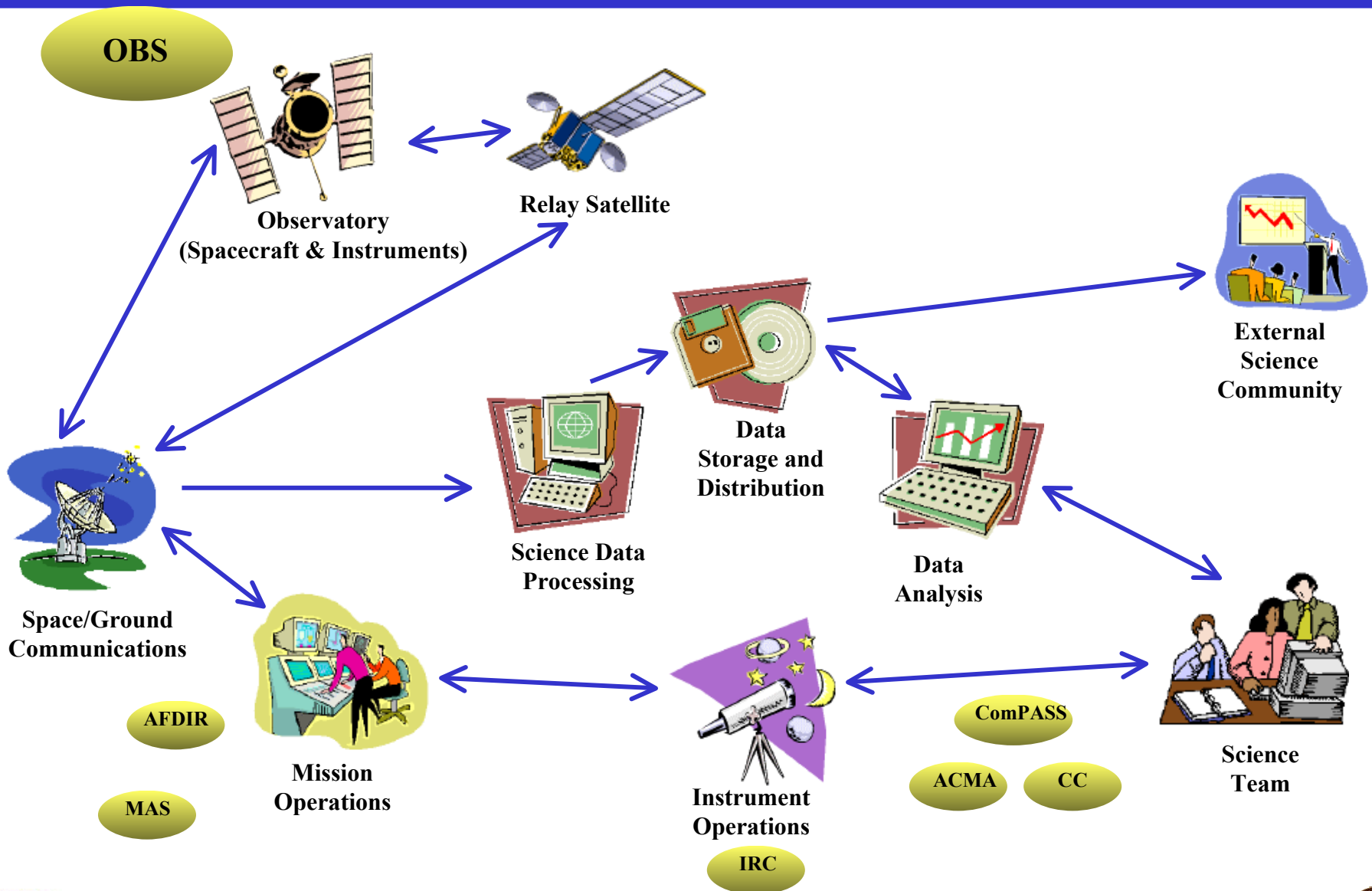**Pipeline Algorithm Markup Language (PAML)**

Instrument Remote Control
FY01 Accomplishments / Plans

- FY01 Accomplishments to Date
  - Completion of Version 3.0 of the IRC framework that includes enhanced instrument and data description capabilities.
  - Presented "Using XML and Java Technologies for Astronomical Instrument Control" at the Ground System Architecture Workshop, El Segundo, CA.
  - Completed Version 3.1 of the IRC framework

- FY 01 Plan vs. Actual Deviations (since semi-annual review)
  - HAWC and COVIR I & T have been postponed indefinitely. The instruments are experiencing fabrication delays.
  - Version 4.0 of the IRC framework is cancelled due to lack community interest.

- Planned Accomplishments for FY02
  - Task is transitioning to GMSEC
  - IRC plans to support infusion for SHARC2, FIBRE, and NIST in FY02
  - IRC expects to fly on the shuttle for COVIR in FY03

Onboard Studies

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Onboard Studies
Overview

- Summarized Description:
  - Research and prototype approaches to innovative architectures that will enable advanced space-based information systems technologies .

- Background / Need:
  - Future missions will increase the complexity of the functions to be performed by FSW. (ie. virtual platforms, constellations, onboard self diagnostics, science feature detection/recognition, science alerting, adaptive scheduling...). In order to perform these complex functions FSW needs an architecture to enable and compliment mission services on the ground.
  - Currently, on-board software environments are drastically different from ground environments. On-board logic is expensive to develop and very difficult to change.

- Benefits
  - Reduced mission operations costs due to increased automation.
    - Increased maintainability and ease of modification via modularity achieved.
    - Common space-ground environment: logic can migrate arbitrarily for optimal performance in any circumstance.
  - Reduced mission risk through greater onboard reactive control.
  - More dynamic on-board autonomy, such as the ability to adapt to various stimuli rather than being fixed and time-tagged, will enable greater scientific return.
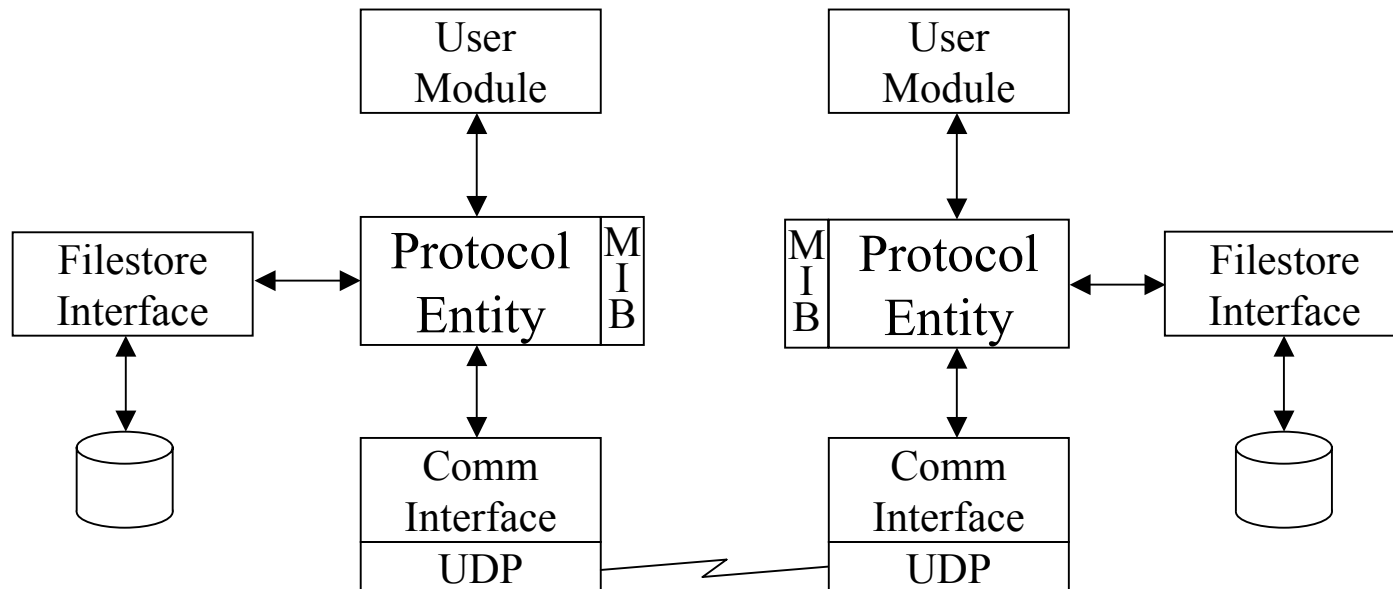
Onboard CORBA Architecture Overview

- The Onboard CORBA Architecture activity is investigating the use of embedded CORBA as a basis for modular and reusable flight software architectures.

- The approach is to replace the custom software used to route CCSDS packets in the MAP flight software with Real-time CORBA as a proof of concept prototype.
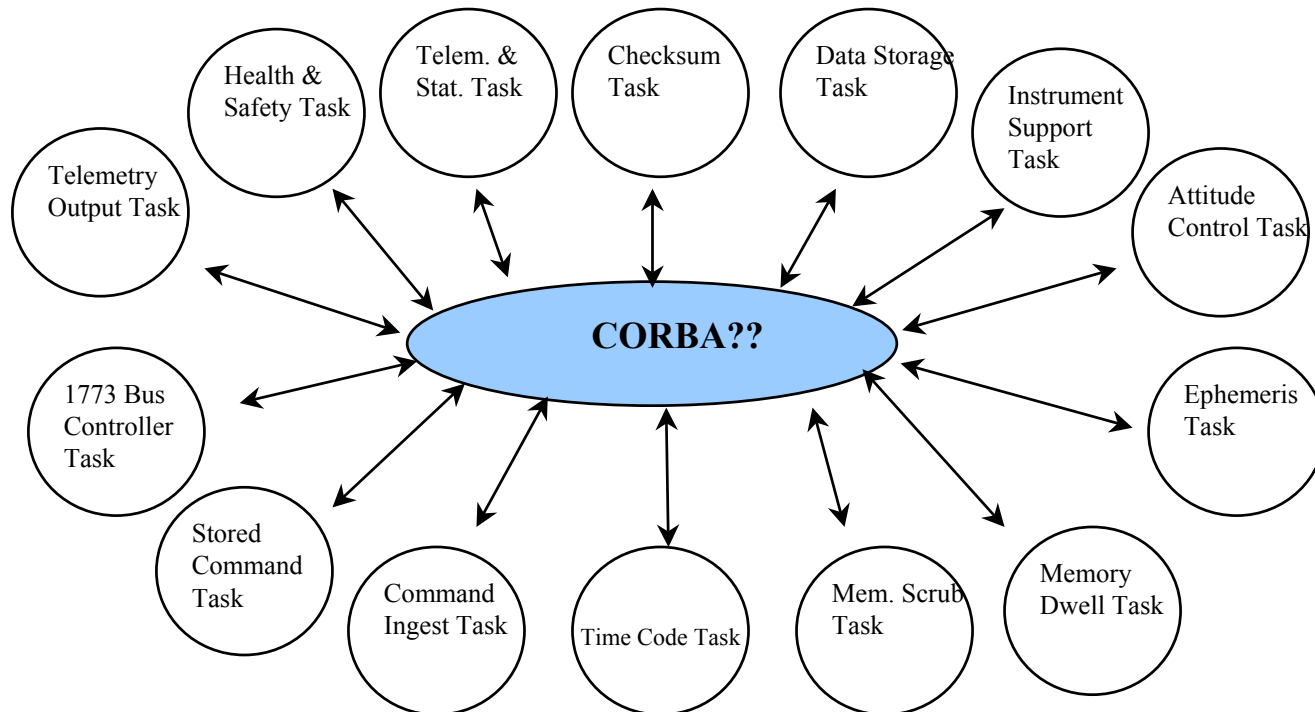
CCSDS File Delivery Protocol (CFDP) Prototype Overview

- The approach is to develop a reusable kernel that can easily be ported to flight software or ground system environments by tailoring the interfaces.

- Initial implementation will create a prototype that includes all core functionality and operates under Windows NT using UDP sockets for communication.

- A flight system implementation was being planned for FY 2002.

```
  ┌──────────┐                              ┌──────────┐
  │   User   │                              │   User   │
  │  Module  │                              │  Module  │
  └────┬─────┘                              └────┬─────┘
       │                                         │
┌─────────┐  ┌──────────┬───┐      ┌───┬──────────┐  ┌─────────┐
│Filestore│←→│ Protocol │ M │      │ M │ Protocol │←→│Filestore│
│Interface│  │  Entity  │ I │      │ I │  Entity  │  │Interface│
└────┬────┘  └─────┬────┤ B │      │ B ├────┬─────┘  └────┬────┘
     │             │    └───┘      └───┘    │             │
    ▱            ┌──┴─────┐            ┌─────┴──┐         ▱
                 │  Comm  │            │  Comm  │
                 │Interface│           │Interface│
                 ├─────────┤           ├─────────┤
                 │   UDP   │───────────│   UDP   │
                 └─────────┘           └─────────┘
```

Onboard Studies
FY01 Accomplishments to Date

- FY01 Accomplishments
  - Onboard CORBA Architecture
    - Completed initial port of all MAP subsystems in the prototype to a CORBA based communication model
    - Presented paper at Object Management Group (OMG) Technical Committee meeting on sending CORBA commands from ground to space.
    - Completed MAP CORBA-based flight software.
  - CFDP Prototype
    - Held Requirements review.
    - Held Preliminary design review.
- FY01 Plans vs. Actual Deviations
  - CORBA-based architecture benchmark tests and white paper "Real-time CORBA Flight Software Architecture" are cancelled in order to complete documentation and clean up of code in preparation for being cancelled at the end of the fiscal year.
- Planned Accomplishments for FY02
  - Task was scheduled to complete in FY02
  - Task is cancelled.

End to End Mission Autonomy Milestone Schedule

	Start Date	End Date	Revised End Date	Notes
5831 - Instrument Remote Control (IRC) Task				
1.1 IRC Framework Version 3.0	4Q FY00	1Q FY01		
1.2 SHARC Integration & Test			Cancelled	#1
1.3 IRC Framework Version 3.1	1Q FY01	2Q FY01	3Q FY01	#2
1.4 SAFIRE Integration & Test	3Q FY01	3Q FY01		
1.5 HAWC Full Instrument Test			Cancelled	#1
1.6 COVIR Integration & Test			Cancelled	#1
1.7 IRC Framework Version 4.0 (supporting standardized language)			Cancelled	#3
5832 - Multi-Agent Systems (MAS) Task				
2.1 SOHO Agent Lab	4Q FY00	1Q FY01		
2.2 Orbit Ground Track component	4Q FY00	1Q FY01		
2.3 XY Plot component	4Q FY00	1Q FY01		
2.4 Agent Status component	4Q FY00	1Q FY01		
2.5 Product component	4Q FY00	1Q FY01		
2.6 Demonstration for Phase I prototype agent for Orbit Determination	4Q FY00	1Q FY01	2Y FY01	#4
2.7 Point-and-click visualization components	4Q FY00	2Q FY01		
2.8 Demonstration of Phase II prototype agent for Attitude Determination	2Q FY01	3Q FY01	4Q FY01	#5
2.9 Improved agent modeling visualization components	2Q FY01	4Q FY01		
2.10 Demonstration of Phase III prototype agent for Tape Recorder Subsystem			Cancelled	#6
5833 - Advanced Fault Detection, Isolation and Recovery (AFDIR) Task				
3.1 CSTAT Phase I design (constellation oriented plots/trending)	4Q FY00	2Q FY01		
3.2 CSTAT Phase I demonstration		3Q FY01		
3.3 CSTAT Phase II design (fault detection and prediction)	2Q FY01	3Q FY01		
3.4 CSTAT Phase II demonstration			Cancelled	#6

End to End Mission Autonomy
Milestone Schedule

	Start Date	End Date	Revised End Date	Notes
5834 - Onboard Studies (OS) Task				
4.1 MAP CORBA-based Health & Safety subsystem	2Q FY00	1Q FY01		
4.2 MAP CORBA-based flight software	4Q FY00	3Q FY01		
4.3 CORBA-based architecture benchmark tests			Cancelled	#6
4.4 White paper "Real-time CORBA Flight Software Architecture			Cancelled	#6
4.5 Embedded JAVA Study	1Q FY01	2Q FY01		
4.6 State modeling validation against FSW simulators	1Q FY00	2Q FY01		
4.7 WIRE State Modeling demonstration phase I	2Q FY01	2Q FY01		
4.8 State modeling validation against FSW simulators			Cancelled	#7
4.9 WIRE State Modeling demonstrations phase II			Cancelled	#7
4.10 Report of WIRE test results to assess modern capability for onboard autonomy			Cancelled	#7
4.11 Onboard Science Data Processing Study			Cancelled	#7
5835 - Common Planning and Scheduling System (ComPASS) Task				
5.1 VOLT Release 3 and Demonstration (mission set & interface extensibility)	2Q FY01	2Q FY01		
5.2 VOLT Release 4 and Demonstration (user-coordination)	3Q FY01	3Q FY01		
5.3 VOLT Release 5 and Demonstration (ground-based observatory)	4Q FY01	4Q FY01		
5836 - Constellation Challenge (CC) Task				
6.1 Concept of Operations Document	4Q FY00	1Q FY01	2Q FY01	#8
6.2 Requirements Document	4Q FY00	1Q FY01	2Q FY01	#8
6.3 Interface Control Document	4Q FY00	1Q FY01	2Q FY01	#8
6.4 Proof-of-Concept Demonstration		2Q FY01	3Q FY01	#9
6.5 Requirements Document - Release 2	2Q FY01	2Q FY01	3Q FY01	#9
6.6 Design Document (Preliminary)	3Q FY01	3Q FY01		
6.7 Prototype Release (basic goal oriented commanding functionality)	3Q FY01	4Q FY01		

End to End Mission Autonomy Milestone Schedule

	Start Date	End Date	Revised End Date	Notes
5838 - An Architecture for Constellation Management Automation Task				
8.1 SOMO Milestone status review		2Q FY01		
8.2 CMA Design & SOMO Milestone status review	1Q FY01	4Q FY01	2Q FY02	#10

Notes:
- Cancelled due to indefinite hardware fabrication delays
- Extension of requirements occurred during FIBRE integration and test
- Cancelled due to user community request
- Additional time was spent on the development of the visualization, agent status component, overall infrastructure, and integrating JPL into the working group
- Additional time spent integrating the agent community
- Cancelled due to termination of task in FY02
- Cancelled due to the budget cut
- Management requested more time be spent in project planning
- Significant staffing changes
- Task was more involved than originally anticipated